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Chemical Impregnation of Trees and Poles for Wood Preservation

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SUMMARY

Chemical impregnations of trees and poles by sap-stream methods have been tried out in one form or another for centuries. Strictly for wood preservation, however, the methods had been frowned upon because they were commercially inadequate.

Investigations made from 1930 to 1940 in North Carolina and South Carolina with a number of methods, 58 chemicals and chemical com-

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binations, and 1,639 trees and 188 poles, and at different seasons of the year, have shown that farmers and other users of wood-lot trees can increase the durability of fence posts, utility poles, and materials for rustic construction with little added expense and labor. For such uses some of the methods proved practical and a few of the chemicals proved effective, but unfortunately none of the methods or chemicals appear faultless. This circular is intended to furnish the information that will be needed by anyone wishing to improve by these methods the durability of wood that is to be used in contact with the ground.

Stepping and capping are simple methods that can be used either separately or together, and can be applied with equipment that is usually available about the farm or home. Stepping is applicable and practical with trees up to 6 inches in diameter; capping can be used for practical treatments of trees up to 8 inches in diameter. Large stepped or capped trees will produce one good 10-foot log. Both methods can be used to some advantage for treating cut poles.

Collar and banding methods are used to treat standing trees. These methods require more materials and labor and are more complicated than either stepping or capping. Both methods are applicable to trees over 5 inches in diameter, preferably for those 8 inches in diameter and over. Banding, more exacting than the collar method, has advantages over the latter that make it preferred for experimental studies. There is a need, however, for a more practical method than either of these for treating large trees.

The other tested methods seem to have only limited and specialized uses. Some of them probably will prove of practical value should a chemical be found which, at amounts not toxic to the tree itself, will repel or control attacking insects.

All the chemicals recommended in this circular are more or less poisonous to human beings and to domestic and wild animals. They should be handled with care to avoid accidents, and persons who are unfamiliar with the dangers to be encountered in handling such compounds should not attempt to handle them without securing expert advice or supervision.

Copper sulfate and zinc chloride, the former at an injection dosage of $\frac{3}{4}$ pound of the salt and $\frac{1}{2}$ gallon of water per cubic foot of wood, the latter at a dosage of 1 pound of the salt to $\frac{1}{2}$ gallon of water, have proved satisfactory as wood preservatives. Both salts are cheap, available locally, and easy to apply, and the presence of each is readily determined. Copper sulfate discolors wood and corrodes iron; zinc chloride, however, does not discolor wood and is only slightly corrosive to iron.

Chromated zinc chloride, a mixture of zinc chloride and sodium dichromate, can be recommended as a wood preservative at an injection dosage of $\frac{3}{4}$ pound of the salt and $\frac{1}{2}$ gallon of water per cubic foot of wood. It has the properties of zinc chloride and in addition is possibly more resistant to leaching.

Sodium arsenite at an injection dosage of $\frac{1}{2}$ pound of the salt and $\frac{1}{2}$ gallon of water per cubic foot of wood is fairly effective, but less satisfactory than copper sulfate or zinc chloride. Its properties are similar to those of zinc chloride with one outstanding exception: It is very poisonous.

Mercuric chloride, although an excellent wood preservative, is unsatisfactory when applied by sap-stream methods, even at injection

dosages of $1\frac{1}{2}$ pounds of the salt per cubic foot of wood, because it distributes poorly. Further, it is very poisonous and relatively expensive.

Ammonium bifluoride, although tested only recently, appears to have advantages that make it recommendable. It seems to permit the wood to dry out more than most other salts used, but otherwise its properties are similar to those of zinc chloride. It has a disadvantage in that it will break down into poisonous compounds. It seems more favorable than ammonium fluoride.

A mixture of copper chloride and arsenic acid, which has had only limited tests and service, has promise of being a highly effective preservative. Injected into the tree, it precipitates in the wood as a stable compound apparently repellent to insects and decay organisms. It possesses most of the advantages of other satisfactory chemicals with the added advantage of permitting the wood to dry out in a way that is comparable to the drying of untreated wood. However, it is poisonous.

Zinc metaarsenite and, especially, ammonium copper arsenite exhibit preserving characteristics that recommend them for further trial.

Absorption of the chemical solutions by pines and yellow poplars takes normally from 2 to 6 hours.

Optimum distribution of the chemical within pines and yellow poplars takes nearly 2 weeks.

Salt-impregnated woods tend to season with only minor checking.

Pine trees can be more satisfactorily treated with preservatives by sap-stream methods than can hardwoods. In the larger diameters, the heartwood and the transition wood of most pines are relatively more durable than those of most hardwoods. Chemical distribution in large trees by sap-stream methods is limited to the active sapwood. Of the trees containing heartwood, therefore, pine trees may be more effectively protected by sap-stream methods against damage by insects and decay, than may hardwood trees.

Pine trees may be treated at any time except during freezing weather, but hardwoods only from early spring to late summer. Late spring and summer treatments generally are more satisfactory than those made at other seasons of the year.

INTRODUCTION

There is a general and constant need in the United States for cheap, durable woods for fence posts, rural utility poles, and rustic construction. Suitable woods of natural durability are relatively scarce, although nondurable but otherwise satisfactory woods are commonly plentiful. It is important, therefore, to develop simple methods and to find inexpensive materials for making the available stock resistant to insects and decay. Investigations have been made, therefore, to find treating methods and chemicals that would be: (1) Destructive or repellent to injurious insects and fungi over a reasonably long time; (2) harmless to man and other warm-blooded animals; (3) easily applied for ready absorption and even distribution of the chemicals within the tree or pole; (4) inexpensive with respect to the chemicals and materials used, and the labor required; (5) noninjurious to the treated wood—that is, containing nothing that will stain or structurally weaken it; and (6) noncorrosive to hardware.

In 1926 (14)² investigations of chemical injections for the control of bark beetle broods were begun by the Bureau of Entomology of the United States Department of Agriculture at the Asheville, N. C., laboratory of the Division of Forest Insect Investigations. These studies, in which bark beetle-infested pines and healthy pines and hardwoods were used, resulted in the development of practical non-commercial procedures for impregnating the wood of standing and freshly cut trees and poles with inexpensive preservatives.

A large number of the treating methods described by earlier investigators were tested from 1930 to 1940, inclusive, and the commonly accepted wood preservatives as well as chemicals that bid fair to be effective were used with pines and several species of hardwoods.

The term "injection" has been commonly used for wood-treating processes, although treatment and impregnation are interchangeably used and are more correct for the methods usually followed.

Explanations of the methods and preservatives used and the conclusions reached are presented in this publication, with special emphasis on the practicability of sap-stream treatments and the feasibility of particular methods and chemicals. It is conceded that none of the methods are faultless, and that even the more practical chemicals have their drawbacks. Although various pine and hardwood species were used, most of the treatments were made with shortleaf pine and yellow poplar, and the conclusions, for the most part, are based on the results of these treatments. The conclusions are not final and similar results may not be obtained in treatments of other tree species. Nevertheless, it is believed that farmers and other users of wood-lot trees can profit by utilizing the information presented.

Many farmers in the southeastern part of the country during the last several years have accepted the general idea of sap-stream treatments, and have used either some of the methods discussed here or variations of them. Thousands of preservative-impregnated posts and poles already have been set out in fence rows and in power- and telephone-line construction.

A green tree or pole treated by sap-stream methods with a preserving chemical absorbs that chemical and distributes it within the wood by means of normal physiological activities. The amount and speed of absorption, distribution, and deposition of the chemical are dependent on: (1) The method of treatment and subsequent handling of the tree or pole; (2) the chemical, its form, water-solubility, and concentration; (3) the amount and condition of the active wood; (4) the reaction of the chemical after it enters the wood; (5) the species and size of the tree or pole; and (6) the season of the year. Weather conditions during treatment and time of day are minor influencing factors. All these points were considered in the impregnation studies, and the practical applications of various treatments are outlined in this circular.

HISTORY

Chemical impregnation of green trees and poles by sap-stream methods is an old idea that has been used to advantage for centuries. As a means of preserving wood, however, it has fallen into general disfavor, primarily because it is not applicable to commercial use.

² *Italic numbers in parentheses refer to Literature Cited, p. 29.*

Since the discovery in 1709 of sap movement in trees (21), chemical impregnation of trees and poles by sap-stream methods has been the subject of investigations, some made to develop means of preserving nondurable woods (7), others to determine ways of staining wood for cabinet work (8), fire-proofing trees (17), introducing essential nutritional elements lacking in trees (12), killing undesirable forest trees (silvicultural practices) (1), and controlling destructive forest and shade-tree insects and diseases (6 and 25). Two very interesting reviews and extensive bibliographies of the history of chemical impregnation of trees are given in recent papers by Carter (10) and May (18).

FACTORS INFLUENCING TREATMENTS

PITCH INTERFERENCE

Probably the most disturbing factor encountered in the injection of chemicals into coniferous trees or poles is "pitching out," which is the excessive flow of resin from freshly cut wood. Unless proper precautions are taken, the pitch exudes, accumulates, and solidifies on the wood surfaces, interfering with chemical absorption. Often, because of the overabundance of pitch, an injection set-up must be renewed, sometimes more than once, before the chemical solution is completely absorbed. Pitch interference, however, can be greatly decreased, usually eliminated, by special handling prior to the time the injection treatment is set up.

Preliminary scoring of the wood near, and preferably below, the point where the chemical solution is to be injected will often result in an exudation of considerable pitch. As a result, the injection set-up can be made and the chemical will be absorbed without interference by pitch. This scoring is accomplished by chopping or sawing a so-called pitch girdle approximately $\frac{1}{2}$ inch deep into the base of the tree about 24 hours before the treatment is made. The pitch oozes from this girdle.

The pitch girdle is not needed if the tree is to be severed from the stump for treatment. Such a tree may be cut a day previous to treatment; then, immediately before the chemical is applied, a disk of wood about 1 inch thick should be sawed from the cut end to expose a fresh pitch-free surface to the chemical solution.

Pitch solvents (alcohols) have been employed, both preliminary to treatment with the preserving chemical and along with the preservative. The results were not always satisfactory. The solvents usually "cut" the pitch, but sometimes apparently damaged the active wood cells as well, seriously interrupting proper conduction and distribution of the preservative.

Pitch interference is most prevalent, and consequently most troublesome, during the spring growing period; but late summer and fall injections of chemicals, as a general rule, can be made without the preliminary precautions regarding pitch control.

In the hardwoods studied, sap interference was not a problem.

HEARTWOOD ABSORPTION

Chemical distribution by sap-stream treatments is generally limited to the sapwood. The treating solutions are seldom absorbed by either

true or physiological heartwood³ except where the solutions are in direct contact with them at the time of treatment. Where there is direct contact, however, the chemical, although distributed a relatively short distance in the heartwood, becomes concentrated there and often prevents the sapwood from getting its proper share of the preservative.

CROWN AND STUMP ABSORPTION

Almost all the injected chemical is absorbed by the woody stem of the tree. Some of it, however, goes into the branches and leaves, and some into the stump and roots. Chemical analyses show that the distribution of the preservative into the crown is relatively light; and examinations of the tops and stumps in the woods indicate that little preservative is lost there, since the branches and stumps from treated trees usually disintegrate as rapidly as those from untreated trees.

These losses of chemical are taken into consideration in the recommended injection dosage for each preservative.

LEACHING

Most of the chemicals useful for sap-stream treatment are water-soluble and therefore subject to leaching. This has tended to discourage the use of such chemicals and the sap-stream-treating methods. Leaching can be counteracted, however, by reducing the solubility of the introduced chemicals or by injecting an excess of the preserving salt.

Some mixtures of water-soluble materials dry and precipitate in the wood as insoluble salts. Such a mixture, copper chloride and arsenic acid, was suggested by Carter⁴ and used in 1940 with promising results. The addition of alkali dichromates to many of the common water-soluble preserving salts is also reported (3 and 9) to reduce leaching from impregnated wood. One such combination, chromated zinc chloride, a mixture of zinc chloride and sodium dichromate, was used in 1936 and has thus far proved satisfactory in service.

The injection of a quantity of the preserving salt in excess of the minimum amount necessary for satisfactory protection of wood, a so-called safety factor, will protect the treated wood until the retained amount is reduced to less than the essential minimum. The recommended injection dosages for most of the satisfactory chemicals used in these investigations were set up on this basis. It remains to be determined by service records whether the quantities recommended are sufficient to insure an acceptable service life, such as 10 years, despite the leaching. Valuable information on leaching also will be made available when wood samples collected in 1941 from service stakes are analyzed quantitatively and the results are compared with results of analyses for samples taken when the stakes were set out.

TREES TREATED

In all, 1,639 trees and 188 poles of 5 pine and 9 hardwood species were treated in these investigations (table 1). The trees included:

³ Physiological heartwood is that woody part of the tree stem in transition from living sapwood to technical heartwood, but which, like the dark-colored technical or true heartwood contains no living elements. In color, however, it is similar to the light-colored sapwood.

⁴ Manuscript report.

1,338 pines, of which 1,194 were shortleaf (*Pinus echinata* Mill.); and 301 hardwoods, of which 157 were yellow poplar (*Liriodendron tulipifera* L.). Of the poles, 105 were shortleaf pine and 83 were yellow poplar.

TABLE 1.—Numbers of trees and poles of various species impregnated with chemicals

Common names of trees	Scientific names	Trees	Poles
		Number	Number
Conifers:			
Loblolly pine.....	<i>Pinus taeda</i> L.....	83	-----
Pitch pine.....	<i>Pinus rigida</i> Miller.....	49	-----
Virginia scrub pine.....	<i>Pinus virginiana</i> Miller.....	4	-----
Shortleaf pine.....	<i>Pinus echinata</i> Miller.....	1, 194	105
White pine.....	<i>Pinus strobus</i> L.....	8	-----
Hardwoods:			
White ash.....	<i>Fraxinus americana</i> L.....	4	-----
River birch.....	<i>Betula nigra</i> L.....	2	-----
Shagbark hickory.....	<i>Carya ovata</i> (Mill.) Koch.....	58	-----
Red maple.....	<i>Acer rubrum</i> L.....	13	-----
Black oak.....	<i>Quercus velutina</i> LaM.....	34	-----
Red oak.....	<i>Quercus rubra</i> L.....	19	-----
Scarlet oak.....	<i>Quercus coccinea</i> Muench.....	11	-----
White oak.....	<i>Quercus alba</i> L.....	3	-----
Yellow poplar.....	<i>Liriodendron tulipifera</i> L.....	157	83
Total.....		1, 639	188

The pines ranged in size from 2 to 20 inches in diameter at breast height and the hardwoods from 4 to 16 inches. The majority of trees, however, were in one of the following diameter classes: 4-inch, 5-inch, 8-inch, 12-inch, and 16-inch. All the poles were 6, 8, 12, or 20 feet long, cut from 5-inch trees.

Most of the trees under 8 inches in diameter were composed entirely of sapwood. As sap-stream treatments result in and are dependent on chemical impregnation of sapwood, each species was separated into two categories, one including trees up to 8 inches in diameter and the other, trees 8 inches and over. The amount of chemical applied to a tree in the first category was based on its total wood content, whereas that applied to a tree in the second category was based on the sapwood content only.

TREATMENT METHODS

Eight principal treating methods were used. Each was either an older method adapted to modern equipment or an older method used without variation. The methods necessitating a minimum of equipment are considered practical for general purposes, whereas others, which require specialized equipment, are of restricted usefulness.

STEPPING METHOD

The stepping method (fig. 1), probably the earliest method used with cut trees and poles, is a treating procedure whereby the butt end of an upright tree or pole is kept in a container of preservative solution until the chemical is absorbed. The tree is retained upright by lodging its crown in the canopy of a neighboring tree. A pole is leaned against a tree, wall, or other suitable object. Wooden liquor kegs, butter churns, or pickle buckets make excellent containers for any preservative solution, and especially for solutions corrosive to metals.

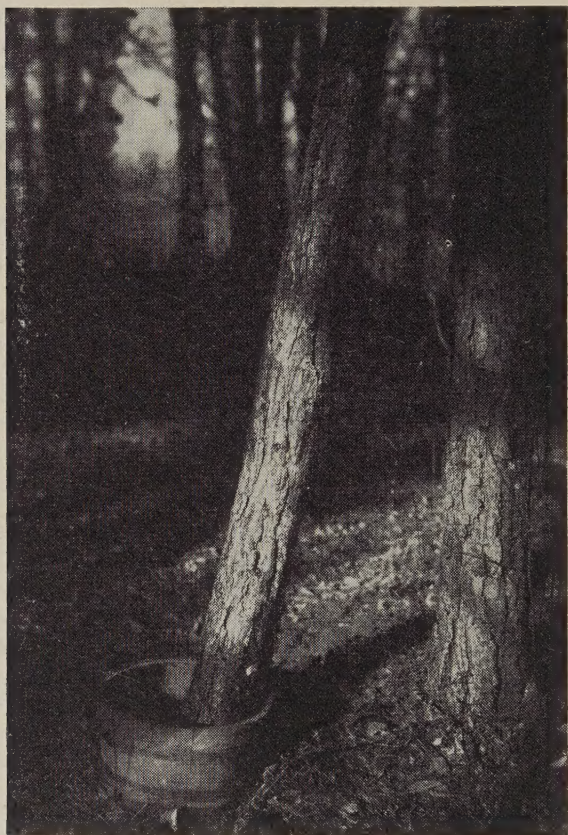


FIGURE 1.—The stepping method. A shortleaf pine tree stepped in a container made from a wooden keg.

In all instances it is advisable to make the treatment with freshly cut stock. The treating ends of trees or poles that have been cut a day or more should be freshened immediately before treatment by removing a 1-inch disk of wood. In the case of hardwoods, covering the cut ends with wet burlap or moss should tend to keep them in a satisfactory condition.

CAPPING METHOD

Capping (fig. 2) is a variation of a method commonly referred to as the Boucherie method for injecting chemicals into trees and poles. By this method the butt end of a felled tree or one end of a pole is encased in a cap-container which holds the solution in direct contact with the wood until it is absorbed. The combination cap and container can be made from a length of automobile inner tube, the ordinary-sized passenger car tube being satisfactory for use with trees or poles up to 8 inches in diameter. The same type of tube can be used for treating larger trees and poles if their ends are shaved down, provided an annual growth ring or two of sapwood is left exposed to the chemical, or a tube from a truck tire can be used. Selected discarded inner tubes

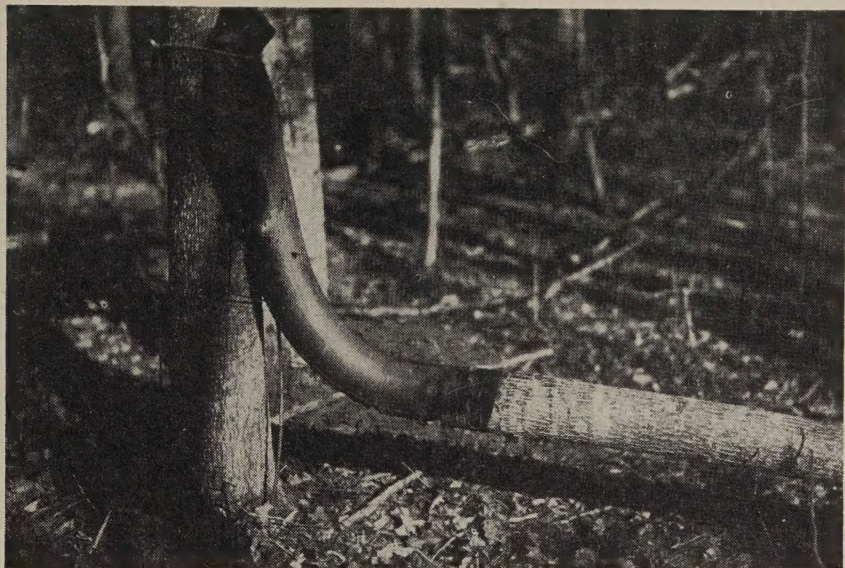


FIGURE 2.—The capping method. A yellow poplar tree capped with a section from an automobile inner tube.

are satisfactory for this purpose. Under pre-war conditions these were readily available at little or no cost, and this will probably be the case after the war.

In setting up the treatment, one end of the tube is pulled over the smoothed end of the tree or pole for from 4 to 8 inches and bound tightly with a long 2-inch-wide band cut from another inner tube. A piece of 12-gage iron wire drawn firmly about the tube and hammered into depressions in the wood is also satisfactory as a binder. For the most satisfactory conservation of the chemical all wood surfaces that were shaved down to accommodate a small tube should be covered with the cap. By peeling the bark from the end of the tree or pole and shaving down all rough wood surfaces, the attachment of the cap is made easier and leaks are less likely to occur. If the bark of pines is stripped approximately 24 hours in advance, pitch will collect on the peeled surface and will cause the cap to stick firmly to the wood and prevent most leaks. If the cap is to be placed on a freshly barked tree or pole, a coat of roofing compound applied to the barked surface will prevent all leaks. After the cap has been fastened on, the free end of the tube is raised and fastened to an adjacent sapling or stake, and the chemical solution is poured into it, completing the set-up. The tree need not be moved into any special position, except for convenience in placing and binding the cap. The capped ends of poles (26) should be elevated to increase the head of liquid and thereby accelerate treatment. After the chemical is absorbed by the wood the tube may be removed and used in treating other trees or poles.

Unfortunately, at present there is no known nonrubber substitute for inner tubes for capping, hence the method is probably not practicable for the duration of the war.

COLLAR METHOD

The collar method (fig. 3) for treating standing trees is in reality a variation of the early style of banding. A groove, or kerf, is made with a saw, axe, or chisel, usually near the base of the stem, and approximately $\frac{1}{2}$ inch deep in the center of a 10-inch-wide bark-stripped band. The kerf should not completely encircle the stem, about 1 inch of clear wood being left between the two ends. A collar of waterproof material is fastened around the tree at the kerf, and the preservative solution is poured into this collar to be absorbed by the tree.

A simple and practical collar may be made from a long piece of an inner tube, slit lengthwise along the inner circumference. The resulting long, wide belt is placed once around the tree so that the two edges of the collar fit snugly to the tree. After it is fastened to the tree stem, the collar bulges out at the center, affording ample room, even without stretching, to hold all the liquid preservative at one filling. The ends of the collar should overlap at the place where the horizontal groove has not been cut through and should be nailed tightly to the tree under a narrow strip of galvanized iron. The bottom of the collar should be bound tightly to the stem immediately below the kerf with several turns of a long 2-inch rubber band cut from another tube. A tighter adherence of the collar below the groove can be assured with conifers by stripping off the bark a day before the kerf is cut, or with all trees by applying a coating of asphalt roofing compound to the wood surface below the bottom edge of the kerf just before putting on the collar.



FIGURE 3.—The collar method. A pitch pine tree treated with a closed collar cut from an automobile inner tube.

The collar may have its top edge bound tightly to the tree with banding material, either after the chemical solution is poured into it or before, provided a small opening is allowed for filling. Thus rain is prevented from diluting the solution or washing it out. The chemical solution is also guarded from animals.

An open collar is one whose top edge may fit snugly, but not tightly, to the tree. Its contents are more likely to become diluted, washed out, contaminated with foreign materials, or consumed or spilled out by animals than those of a closed collar. It can be used safely, nevertheless, where the absorption time is only a matter of a few hours, where the likelihood of sudden heavy showers is at a minimum, and where it can be protected from animal damage until the solution is completely absorbed.

Any tough waterproof fabric (16) can and should be used in place of rubber for collar assemblies as long as rubber is scarce and is such a national necessity.

BORE-HOLE METHOD

Trees may be treated by the bore-hole method (fig. 4) by making holes in the tree stem and inserting a chemical into these holes. There are numerous variations of the method. That found most satisfactory for wood preservation consists in boring 1-inch holes in the base of the tree stem, tangentially and downward for 4 to 6 inches through the sapwood, exposing considerable conducting wood and at the same time providing convenient receptacles for the chemical.

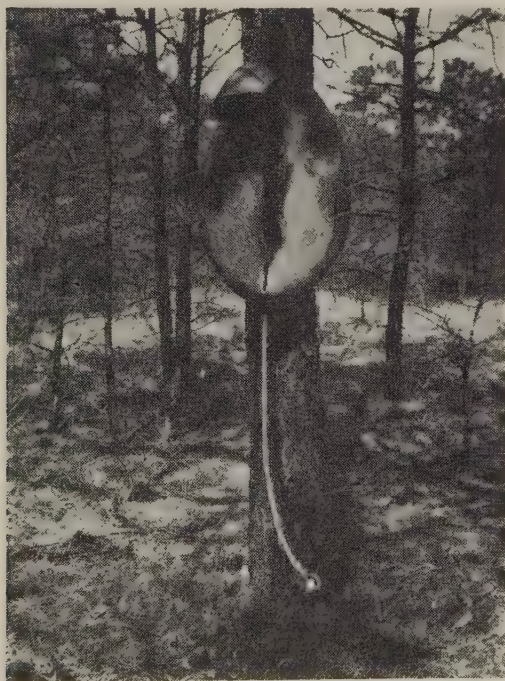


FIGURE 4.—The bore-hole method. A pitch pine tree treated by bore holes (connected internally), an automobile inner tube being used for a container.

While two holes are satisfactory for a 5-inch tree, more are required for larger trees, the rate of increase being two holes for every 5-inch increase in tree diameter. The holes should be on the same or nearly the same level, and may be connected or separate. If the holes are connected, all but one are closed with shallow plugs, and the remaining hole is closed with a stopper having a smaller hole through it. A glass or copper tube is run through this stopper and is connected by $\frac{1}{4}$ -inch rubber tubing with the preservative container, which usually is tied to the tree, above the uppermost hole. The solution is siphoned from this container or run by gravity from an outlet in its base. If the holes are not connected, each is joined by a tube with the solution container or containers.

A simple and satisfactory container can be made by cutting an inner tube across at the valve stem, removing the stem, and inserting it, with the valve removed, on the outside circumference of the tube, midway between the two ends. The container is suspended, often from a branch stub, by tying the two ends together, with the valve stem hanging down. The chemical is poured into the container at either of the two ends and runs out the valve stem, through the connecting tube, and on into the bore hole.

Glass and crockery jars or jugs should be used as containers during the period of vital rubber shortage.

BANDING METHOD

Banding (fig. 5) is a variation of an old procedure of treating standing trees, the primary difference between the two being that the injection kerf in banding is cut spirally around the tree, instead of horizontally as in the older method.

The spiral kerf or groove is sawn or chiseled approximately $\frac{1}{2}$ -inch deep into the wood, near the center of a 10-inch-wide, barked, spiral zone close to the base of the tree, the ends of the groove overlapping an inch or so. A $\frac{1}{4}$ -inch hole is next bored through the wood from one end of the groove, opening on the surface of the bole, 2 or 3 inches away, and one end of a section of $\frac{1}{4}$ -inch rubber tubing is run all the way through it. A piece of stout rubber banding material⁵ is stapled tightly to the tree over the spiral groove so that when in place the band is stretched to about one-half again its original length.⁶ The container of preservative is fastened to the tree above the band, and the loose end of the rubber tube is connected with it. The solution is thus siphoned or run by gravity into the groove. A container such as described for the bore-hole method is satisfactory.

Occasionally leaks will develop under the band, usually where the wood surface is rough. They can be stopped with additional staples or with nails. Often, with conifers, leaks can be prevented by making

⁵ A rubber band with the following specifications supplied by a cooperating rubber company has been found satisfactory:

1 $\frac{3}{4}$ inches wide, $\frac{3}{4}$ inch thick in the center, and $\frac{9}{16}$ inch thick on the outer margin, 38-40 durometer hardness (Type A Shore durometer), 2,500 pounds per square inch tensile strength, 650 percent elongation.

⁶ A staple made of No. 11 wire with a spread of 2 $\frac{1}{2}$ inches and a leg length of 1 $\frac{3}{4}$ inches is satisfactory.

An iron bar $\frac{1}{4}$ inch by $\frac{1}{2}$ inch and 3 inches long, with an open slot at each end, fastened down with two 6-penny nails makes a good staple. This bar may be removed and it and the entire rubber band are available for reuse. The staples hold the rubber band at its two ends.



FIGURE 5.—The banding method of tree treatment. A yellow poplar tree banded with a special rubber banding material, an automobile inner tube being used for a container.

the bark-stripped spiral 24 hours before the groove is cut so that the exuding pitch will become tacky and the rubber band will stick to the tree. Asphalt roofing cement can also be used immediately above and below the injection groove before the band is placed in position.

While there are substitutes for inner tubes as containers, there is nothing that has proved satisfactory as a substitute for the rubber banding material described above.

DRY-PACKING METHOD

Dry-packing (fig. 6) is a method of applying a chemical in dry or paste form to a standing tree. A 10-inch-wide horizontal strip of bark and phloem is removed from around the base of the tree. Cuts may but do not have to be made into the wood within this barked area. The chemical, in a crystal, powder, or paste form, is held against the exposed wood beneath a waterproof wrapping material, such as a rubber band made from an inner tube or a strip of oilcloth, until the chemical is absorbed into the sap-stream.

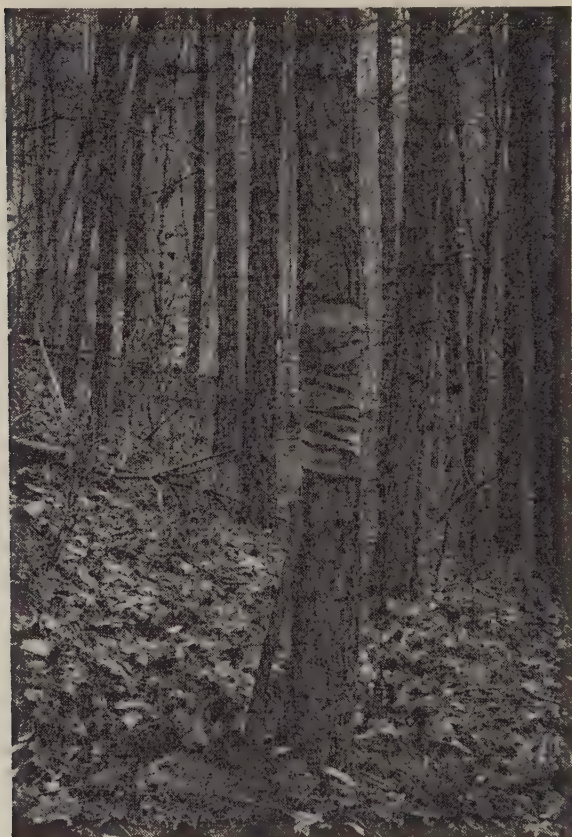


FIGURE 6.—The dry-packing method. A shortleaf pine tree dry-packed with a wrapper made from an automobile inner tube.

MISCELLANEOUS METHODS

Numerous other procedures and variations of the methods already explained were also tested. All are interesting but generally impractical.

Root injections can be made either by severing one or more of the larger roots and capping each with rubber tubing, or by splitting the wood of one or more roots and dropping the chemical into the crack in a dry or liquid form. Complete absorption but streaked and unsatisfactory distribution of the preservative is the usual result.

Injections made by dropping small quantities of a dry and soluble or a liquid chemical into incisions cut at intervals around the stems of trees with a pointed maul result in complete absorption but streaked and poor distribution of the chemical.

Incomplete girdle treatments can be made either by partial banding or by placing collars over discontinuous grooves in the tree stems. For partial banding the grooves are cut into the wood on a spiral and covered by a continuous rubber band and are joined to one another internally by $\frac{1}{4}$ -inch-bore holes. One hole is bored to the outside for introduction of the chemical which, as in banding, can be siphoned or

drained from the container. In the collar method the discontinuous grooves are on a horizontal plane and need not be connected internally. By either method the chemical is distributed in streaks, the amount of streakedness depending somewhat on the percentage of the circumference that is grooved.

None of these miscellaneous methods are practical for wood preservation, yet they do have a potential value. They will be useful should a chemical be found which, when injected, is harmless to the tree but is repellent or poisonous to destructive insects.

Other variations of banding were set up, in all instances with pines. The trees used in applying the banding method of impregnation were of three different categories: (1) Trees with the bark removed to a height of 20 feet; (2) trees with crowns cut out at a height of 20 feet; and (3) trees with the crowns cut out at 20 feet and the stems barked from the base to the top. Also, two unbarked and untopped trees were banded at a height of 15 feet from the ground.

Chemical distribution was satisfactory in the barked trees, as evidenced by the bolts cut from these trees and used in service. They are as well preserved after 5 years as those cut from regularly banded trees. In trees in which the tops were cut out but the boles not barked, the chemical concentrated near the base, and none was found more than 3 feet above the point of injection. These trees were felled and left in the woods. Even though chemical was found only in the lower part of the stems, the entire stem is still sound after 5 years' exposure. In the barked and topped trees the chemical was distributed the full length of the stems. These trees were felled and the stems of two of them were cut up and used as fence posts. All the posts are well preserved. One of the pines banded at 15 feet was well impregnated with preservative down to the base and up to a height of 20 feet. An expected heavy amount of chemical was retained at 15 feet, and service-test sections of this tree are in excellent condition. Absorption of the chemical solution in the other high-banded tree was very poor, but distribution of the amount absorbed was satisfactory. Only the bolt cut at the 15-foot height, however, is still in good condition.

Several pines with the bark removed to a height of 20 feet were stepped, and chemical absorption occurred at the usual rate, with the exception of two whose injection ends were sealed over with beeswax before treatment, having no cut wood cells exposed. The waxed trees took several times as long to absorb the solutions as did normally cut trees. Chemical distribution was satisfactory in all the trees, and sections of the trees are holding up well in service.

Occasionally a chemical injected into a standing tree by the collar method, or some similar method, will kill a neighboring tree and partly impregnate that tree with the chemical. This is a result of root grafts, and pines as far as 20 feet from a treated tree have been so affected.

THE METHODS AS APPLIED TO TREES

Each recommended method has its particular advantages, but from the practical standpoint of inexpensively treating nondurable woods with preservatives some methods are better adapted than others.

Stepping, for example, is a simple and cheap method for treating trees up to 6 inches in diameter, and the resulting chemical distribution is very satisfactory. Stepping is a possible method even with trees 8 inches in diameter and larger, but is generally impractical be-

cause of the weight and bulkiness of such trees. In a large tree the chemical usually fails to rise high enough to produce more than one well-treated 10-foot log. This log, however, is exceptionally well impregnated because the heartwood for about a foot from the base has absorbed a large quantity of the preservative. Such a log would make an excellent corner post. Service tests show that, as regards the results, stepping is very satisfactory.

Capping, too, is a recommendable procedure for treating trees up to 8 inches in diameter and can be used readily and as a supplemental procedure to stepping. Capping, as a rule, first results in streaked distribution of the injected chemicals, probably because portions of the crown and stem of the tree are against the ground and shaded, and transpiration and evaporation are reduced on the lower side; consequently optimum distribution of the preservative is prevented on that side. While this early streaked distribution is a drawback, it is largely offset by chemical movement in the wood during the seasoning period. Streakedness can be compensated for, too, by injecting an excess of the chemical. As in stepping, the chemical fails to be distributed satisfactorily more than 10 feet up the stem in the larger capped tree, since the sapwood and heartwood for about a foot from the base absorb most of the chemical. Usually one excellent 10-foot butt log is produced. In service, bolts and logs from capped trees have held up well.

The collar method can be used to treat trees of all sizes, especially those from 8 to 12 inches in diameter; but it is impractical with trees less than 5 inches in diameter and questionably reliable with trees over 12 inches. At present the collar method and the closely related banding method are the only effective means for treating more than the butt log of trees 8 to 12 inches in diameter, and with such trees these methods provide better general chemical distribution than either stepping or capping. Trees treated by the collar method, and bolts and logs from such trees, are well protected against insects and decay.

The bore-hole method can be used to treat trees of any size, but chemical distribution and hence preservation are usually streaked. As a consequence, and because the method is somewhat tedious to apply, it is not considered practical. The method is used successfully, however, by horticulturists and arboriculturists for treating unhealthy (chlorotic) trees. On the other hand, the method and variations of it are used by charlatans probably more often than all other methods combined, in illegitimate and high-priced practices of "curing sick trees by medication." Too often such use of the bore-hole method has resulted in more damage than good.

Banding is applicable to trees from 5 to 12 inches in diameter, but is a cumbersome procedure with trees smaller than 5 inches, and it is generally difficult to make the band leak-proof with trees of over 12 inches. Banding is more rapid than the collar method with 5- to 8-inch trees, but slower with large trees. The method has a few minor advantages which suit it better to experimental work than the collar method and, as a consequence, nearly three-fourths of all the treatments in these investigations were made by banding. The method gives good results, but for practical uses it is less expedient than the collar method.

Dry-packing is a rather poor method for wood impregnation. Absorption of the chemical must depend on a physical reaction be-

tween the dry or paste chemical and the sap, and a liberal amount of sap is necessary to dissolve the relatively large amount of chemical present. This is in contrast to treating methods employing water solutions which readily flow into the sap-stream. By cutting into the sapwood and applying the chemical to these cuts, absorption takes place more rapidly. Some tests were made of the dry-packing treatment for wood preservation; others, however, were made in connection with a winter project to determine whether tree activity (bud opening and wood-cell production) could be completely and immediately prevented. Where distribution occurred, the chemical was streaked, and wood preservation was very unsatisfactory. The pines apparently were killed immediately but the hardwoods leafed out in the spring.

There is a need for a more practical and effective method of treating large trees than has thus far been developed, especially trees over 12 inches in diameter. It is conceivable that a method found satisfactory for such trees might be used with equal satisfaction with trees of the smaller sizes and be more suitable than any of those discussed here.

THE METHODS AS APPLIED TO POLES

Stepping of poles was tested to a limited extent. Some poles were stepped with the butt ends down until the solutions were absorbed, others with the small ends down. All were then seasoned in a vertical position, half of each group with the treated ends down and half with the treated ends up. Other poles were stepped for only a few hours before they were turned, end for end, and then kept in the containers until the solutions were completely absorbed. They were seasoned like the first set, half of each group with the butt ends down and half with the small ends down.

Cursory examinations indicated good distribution of the chemical. As the poles have been in service for only 2 years, insufficient time has elapsed to judge the results.

Nettles (19) advocates a procedure called the trough method of stepping green pine poles, and his preliminary investigations indicate that the method described by him may be used to advantage for preservation purposes.

The capping method of impregnating poles thus far has been disappointing, probably because it results in streaked distribution of the chemical and its accumulation near the treated ends. The poles on which capping was used were all seasoned in the position in which they were treated, nearly horizontal, and no attempt was made to remedy the streakedness. Wirka (26), however, reported very encouraging results from capping of posts for fences.

Capping is used by some commercial concerns to treat large poles (over 10 inches in diameter) which usually are partly seasoned. These concerns use artificial external pressure and special treating apparatus so as to get the chemical well distributed within the pole in a relatively short time.

CAUTIONS REGARDING HANDLING OF CHEMICALS

All the chemicals that were found to be effective when applied by these methods are more or less poisonous to human beings and to domestic and wild animals. Care should be exercised to avoid accidents

either through handling the chemicals or by leaving them exposed where children or livestock might have access to them. Splashing of liquid on the skin or inhalation of dust while handling dry powders should be avoided. Containers that have been used for mixing or applying chemicals should be stored in a safe place if they are to be used again, or destroyed. Any excess liquid left after treatment is completed should be disposed of by digging a pit into which the chemical can be poured and covered with soil. Such liquids should never be poured into streams or ponds where they will endanger humans, livestock, or fish.

CHEMICALS TESTED

Twenty-nine organic and 29 inorganic chemicals and chemical combinations were used in these investigations. Unfortunately, none of the organic chemicals proved satisfactory, and only 10 inorganic chemicals were either satisfactory or showed promise of being effective as preservatives when applied by these methods.⁷

All the chemicals were tested as water solutions; one was tested also as a paste, and two were tested dry. The water solutions were far more effective than the same chemicals used in the paste or dry form. It was found, as well, that the concentration of the solution was of no particular importance with respect to its absorption and distribution so long as the salt remained in solution until it was absorbed. In general, the amount of water necessary to dissolve the salt readily and keep it in solution at the lowest temperature encountered during treatment, was satisfactory. A further dilution of the solution or an addition of water after absorption did not appreciably affect dispersal and final allocation of the chemical.

The chemicals tested are shown in the following lists:

Organic Chemicals Used (Within the Limitations of These Tests, None of Them Was Satisfactory)

Acetone (CH_3COCH_3)	Methenamine ($\text{C}_6\text{H}_{12}\text{N}_4$)
Beta-naphthol ($\text{C}_{10}\text{H}_8\text{O}$)	Nicotine ($\text{C}_{10}\text{H}_{14}\text{N}_2$)
Butanol ($\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$)	Nicotine sulfate ($\text{C}_{10}\text{H}_{14}\text{N}_2 + \text{H}_2\text{SO}_4$)
Chloral hydrate ($\text{CCl}_3\text{CHO} \cdot \text{H}_2\text{O}$)	Orthodichlorobenzene ($\text{C}_6\text{H}_4\text{Cl}_2$)
Cresol ($\text{C}_6\text{H}_4\text{OHCH}_3$)	Paraldehyde ($\text{C}_6\text{H}_{12}\text{O}_3$)
Ethyl mercuric chloride ($\text{C}_2\text{H}_5\text{HgCl}$)	Pieric acid ($\text{C}_6\text{H}_5\text{O}_7\text{N}_3$)
Ethyl mercuric phosphate ($\text{C}_2\text{H}_5\text{Hg}_3\text{PO}_4$)	Potassium salicylate ($\text{HOC}_6\text{H}_4\text{COOK}$)
Ethyl mercuric chloride ($\text{C}_2\text{H}_5\text{HgCl}$)	Pyridine ($\text{C}_5\text{H}_5\text{N}$)
Formaldehyde (HCHO)	Rotenone ($\text{C}_{23}\text{H}_{22}\text{O}_6$)
Guaiacol ($\text{C}_7\text{H}_8\text{O}_2$)	Sodium orthophenylphenate ($\text{C}_6\text{H}_5\text{C}_6\text{H}_4\text{ONa}$)
Hexane ($\text{CH}_3(\text{CH}_2)_4\text{CH}_3$)	Sodium pentachlorophenate ($\text{C}_6\text{Cl}_5\text{ONa}$)
Kerosene	Sodium tetrachlorophenate ($\text{C}_6\text{HCl}_4\text{ONa}$)
Kerosene and creosote	Thymol ($\text{C}_{10}\text{H}_{14}\text{O}$)
Kerosene and pyridine ($\text{C}_5\text{H}_5\text{N}$)	Turpentine
Methanol (CH_3OH)	

Inorganic Chemicals Used and the Comparative Results Obtained

Satisfactory

Chromated zinc chloride (81.5 percent ZnCl_2 and 18.5 percent $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$)	Copper sulfate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$)
	Zinc chloride (ZnCl_2)

⁷ A large number of these chemicals were used either with infested pines in studies of bark-beetle control or with healthy pines and hardwoods in toxicity studies of living trees. Some otherwise would not have been used.

Some of the chemicals used undoubtedly have preservative value. However, because methods followed in these tests, the amounts of chemicals used, and the number of trials made were limited, the preservative values of the chemicals were not indicated.

Promising

Ammonium bifluoride (NH_4HF_2)	Mercuric chloride (HgCl_2)
Ammonium copper arsenite	Sodium arsenite ($\text{Na}_2\text{HAsO}_3 \cdot x\text{H}_2\text{O}$)
Ammonium fluoride (NH_4F)	Zinc metaarsenite ($\text{Zn}(\text{AsO}_2)_2$)
Copper chloride and arsenic acid ($\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ and H_3AsO_4)	

Unsatisfactory

Ammonium hydroxide (NH_4OH)	Sodium fluoride and mercuric chloride . (NaF and HgCl_2)
Barium chloride ($\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$)	Sodium hydroxide (NaOH)
Hydrogen chloride (HCl)	Sodium nitrate (NaNO_3)
Potassium cyanide (KCN)	Sodium phosphate ($\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$)
Potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$)	Sodium selenate ($\text{Na}_2\text{SeO}_4 \cdot 10\text{H}_2\text{O}$)
Potassium nitrate (KNO_3)	Sodium selenate and copper cyanide ($\text{Na}_2\text{SeO}_4 \cdot 10\text{H}_2\text{O}$ and $\text{Cu}(\text{CN})_2$)
Sodium arsenate ($\text{Na}_2\text{HAsO}_4 \cdot 7\text{H}_2\text{O}$)	Sodium sulfide ($\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$)
Sodium borate ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$)	Zinc sulfate ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$)
Sodium dichromate ($\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$)	
Sodium fluoride (NaF)	
Sodium fluoride, dinitrophenol, potassium dichromate, sodium arsenate, and gum arabic (NaF , $(\text{NO}_2)_2\text{C}_6\text{H}_3\text{OH}$, $\text{K}_2\text{Cr}_2\text{O}_7$, $\text{NaHAsO}_4 \cdot 7\text{H}_2\text{O}$ + gum arabic)	

CHEMICAL DISTRIBUTION

Good distribution of a chemical in a tree or pole is of importance in sap-stream treatment, because good preservation is dependent on it. Some procedures for determining distribution, qualitatively and quantitatively, have proved useful in the investigations as well as in actual practice.

Within limits, insect and decay activities or their absence reveal the absence or presence and abundance of a preservative in the wood. Staining of wood by an injected chemical denotes the presence of the chemical; and the density of the stain roughly indicates its abundance. Color reaction of an injected preservative with a chemical indicator determines the occurrence of an injected salt, whether the salt itself stains the wood or not. Most of these reactions are positive, that is, the treated woods change to characteristic colors; some, however, are negative, and the treated woods remain unchanged, while the untreated woods take on distinct colors. Others are such that both the treated and untreated woods change to colors that are contrasting.

Water-soluble dyes have been injected along with some preservatives in attempts to determine chemical distribution. To a limited extent they were helpful, since their presence in the wood roughly revealed the presence of the chemicals. Unfortunately, they cannot always be depended on. Analyses of the wood often disclosed the chemical where no dye was apparent, whereas in other instances where the dye was present no chemical was recovered.

Reliable determinations of chemical distribution can be made by quantitatively analyzing small samples of wood taken from the treated tree or pole. Such analyses of samples from various heights along the tree's stem and at various depths into the bole provide measurements of distribution of the preservative throughout the tree. Increment cores make satisfactory samples, and as they are relatively small, a tree or pole can be bored periodically without appreciably weakening or otherwise injuring it.

Numerous analyses of cores from pines and yellow poplars for copper sulfate content were made at the Asheville, N. C., laboratory by a procedure developed by R. H. Carter of the Division of Insecticide Investigations. This procedure will be briefly described later. Quantitative analyses of many other wood samples from trees impregnated with copper sulfate, mercuric chloride, zinc sulfate, sodium arsenite, and sodium fluoride were made in the Washington, D. C., office of the Division of Insecticide Investigations by methods described by Carter, Capen, and Cassil (11).

Quantitative analyses to determine the movement of an introduced chemical in trees, and thus to determine the time needed for optimum distribution of the preservative, were made of samples taken from pines in midsummer 6 hours, 12 hours, 24 hours, 2 days, 4 days, 7 days, and 2 weeks after they were injected. Two types of sampling were used. By one, the same trees were sampled each time and by the other, one group of trees was sampled for each period. Consequently, each tree of the first type was bored several times at definite positions along the stem, whereas in the case of the second type each tree was bored only once and at only one of those definite positions. Either procedure is satisfactory, since, for practical purposes, numerous samples from a few trees are as suitable as single samples from many trees, and an accumulation of bore holes was found not to interfere materially with gross chemical movement within the tree. The analyses revealed that further chemical movement in pines becomes insignificant between 1 and 2 weeks following the treatment. Two weeks, therefore, is considered sufficient elapsed time for optimum distribution of the preservative. Less detailed tests of the same nature with yellow poplar resulted in similar reaction for that species, and suggest a reasonable possibility that no more time is necessary for optimum distribution in any tree that will satisfactorily absorb the preservative.

INJECTION DOSAGES

For good preservation, it is not only necessary to use a proved toxic chemical that distributes well, but enough of this chemical to give lasting protection. Hence, a satisfactory minimum injection dosage for each commendable preservative was sought. Injection dosage, as used here, means the amount of a chemical (weight of chemical and volume of water) injected per cubic foot of conducting sapwood. The minimum amount needed for each chemical can finally be determined only through service tests. Prior to completion of such tests, however, it was found that injection dosages necessary for positive preservation were much in excess of those suggested by toxic values determined through laboratory tests of the chemicals (15). As later explained, one very toxic salt, mercuric chloride, needed to be injected in amounts even greater than those for chemicals less toxic in order to even approach the protection afforded by these less toxic chemicals.

The determined minimum dosage suggested for each effective chemical includes an amount of the chemical equal to or exceeding both that which may be lost through leaching and that needed to overcome factors which tend to interrupt smooth and equal distribution of the preservative. This extra amount is the safety factor, which, for any of the satisfactory preservatives tested, may be greater than necessary,

but yet not so much so in any instance as to make the use of that chemical financially or otherwise impractical. Possibly longer and additional service tests will suggest changes in the amounts.

SERVICE TESTS

Service tests were made of all treatments. In making them, some trees were not moved after impregnation but left in the woods, either standing or on the ground; others were cut into poles and used for rustic construction or stored for seasoning; still others and all treated poles were cut into short bolts and either partly buried vertically in the ground or laid horizontally on the ground surface.

Field observations of each treatment were made at irregular intervals from the time the experiment was set up through the period of the tree's or pole's exposure or service. No predetermined time limits for inspection were made, and no cut-and-dried formula was used for determining whether a treatment was satisfactory. A minimum period of exposure or service, however, was deemed advisable before the results of the treatment were used for comparative purposes and considered conclusive. Five years was chosen as this minimum period, and the effectiveness of each chemical was based on its service during that period even though within much less time, often within 1 year, untreated woods break down. Consequently, treatments from 1930 to 1936, inclusive, were grouped in one class from which such determinations were drawn. Treatments made each year thereafter, from 1937 to 1940, were considered separately, in yearly classes. The reliability of results is naturally greatest for the tests in the first class, but some few of the chemicals tested only after 1936 demonstrate favorable qualities which, if the treated material continues to hold up in service, will place them in a category higher than or equal to that of the preservatives now considered most satisfactory and practical.

Evaluation of the results of these tests were not difficult, but it required considerable use of interpolation and personal judgment because of the variation in the service tests used and the general heterogeneity of most other factors involved.

When the field data were being analyzed, each treatment was given a rating for protection against insects and decay, depending on its showing in service. The ratings for each material were averaged, and the averages were placed in tables of variables from which practical conclusions were drawn. Based on those conclusions, each chemical was catalogued as "satisfactory," "promising," or "unsatisfactory." A satisfactory chemical is one that fulfills the major and most important points of the objective; a promising chemical is one which, although fulfilling most of the points, has not yet exhibited as good qualities as is desired—for instance, a chemical which is yet too expensive for use, or one which has been in service only a short time even though it has indicated favorable qualities; and an unsatisfactory chemical is one that has exhibited either poor or definitely injurious properties.

In this circular an effort has been made to indicate the cost of the various treatments by giving the prices for bulk lots of the several satisfactory or promising chemicals. It must be understood that prices of all commodities are variable from year to year. The prices given are for the summer of 1943.

SATISFACTORY OR PROMISING CHEMICALS

COPPER SULFATE

Copper sulfate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) has been used as a wood preservative for centuries and still fulfills most of the requirements of a good preservative, except that it has a corrosive action on metals. It was applied more often during these studies than any other chemical, often serving as a guide for many of the treatments with other chemicals. The minimum injection dosage for copper sulfate usually was used as the starting point for the determinations of minimum dosages of other chemicals.

Copper sulfate, commonly known as bluestone, blue vitriol, or blue copperas, is available at farmers' supply houses as large transparent crystals, small granules, or a powder, for between 6 and 7 cents per pound in bulk lots. It is soluble in water at a rate of over $2\frac{1}{2}$ pounds per gallon, dissolving most readily when in the small granular or powdered forms. Copper sulfate usually discolors wood, a small amount imparting to it a light-greenish-blue shade and a large amount making it dark olive green. Wood discolored by the chemical, however, can be painted over. Copper sulfate also tends to keep the wood abnormally wet, especially when the wood is lying in or on the ground.

Reasonable caution should be observed in handling copper sulfate although it is not so poisonous as are some of the other chemicals that have proved effective when used in the sap-stream injection treatment of wood.

Copper sulfate is corrosive to iron, hence is advisably stored and used in glass, crockery, fiber, wooden, or rubber containers. Small ungalvanized iron nails, such as lath nails, driven into wood treated with bluestone are completely destroyed within 1 or 2 years; heavier materials, such as ungalvanized iron staples cut from No. 9 wire, apparently corrode only on the surfaces, with the result that the surfaces become roughened, making the staples more resistant to removal. The corrosion of the metal is shallow, possibly because of the limited supply of salt in direct contact with it.

The presence of copper sulfate within wood can often be determined by the discoloration of the wood, as mentioned above. In conifers some copper sulfate often mixes with the exuding pitch, imparting an emerald green to streaks or patches of pitch on the wood surface beneath the bark or clinging to the bark when the bark is removed; bright-green resin ducts also indicate the presence of the salt. Copper sulfate within wood is more definitely determined (4) in the field by spraying or brushing the wood with a 1-percent solution of potassium ferrocyanide ($\text{K}_4\text{Fe}(\text{CN})_6 \cdot 3\text{H}_2\text{O}$). When this is done wood containing the preservative becomes dull red; otherwise it retains its original color. The density of the color roughly indicates the abundance of the salt.

Quantitative measurements of bluestone in pines and yellow poplars were made at the field laboratory by the analytical procedure previously mentioned as having been developed by R. H. Carter. This procedure involves cutting the wood sample into small bits, soaking the pieces in distilled water, boiling and then cooling it, adding a 10-

percent potassium iodide (KI) solution, and titrating with a $\frac{1}{100}$ normal solution of sodium thiosulfate ($\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$) in the presence of a starch indicator. The amount of sodium thiosulfate used to cause the color change bears a definite relation to the amount of copper sulfate present.

All treatments with copper sulfate, excepting a few dry-pack applications in 1936 and 1937, were made with water solutions at amounts of from 0.01 pound to $2\frac{1}{2}$ pounds per cubic foot of sapwood. The solutions were readily absorbed and well distributed; only the larger dosages, however, provided satisfactory preservation.

Termites, sawyers, and bark beetles cause no damage to wood containing $\frac{1}{4}$ pound or more of copper sulfate per cubic foot. Pinholes by ambrosia beetles cannot be prevented, however; and ambrosia beetles can even produce broods in wood containing upwards of 1 pound of the salt.

Bolts from trees treated with $\frac{3}{4}$ pound or more of copper sulfate in $\frac{1}{2}$ gallon of water per cubic foot of wood and placed in service in and on the ground for over 6 years are in as good condition as when they were set out in 1935. They show no indications of failure. As a result of these service records, the above is indicated as a minimum injection dosage for satisfactory and practical sap-stream treatments of trees up to 8 inches in diameter.

ZINC CHLORIDE

Zinc chloride (ZnCl_2), sometimes called butter of zinc, was used rather extensively in these investigations. Like copper sulfate it is an "old-time" preservative that has seen lots of service, and in this country it has received more attention than copper sulfate.

Zinc chloride costs from 7 to 8 cents per pound in bulk lots and is available at most farmers' supply houses. It is a very deliquescent white granular salt which must be stored in tightly sealed containers to be kept dry. It can also be satisfactorily stored as a solution of 50-percent strength. Over 16 pounds of the salt will dissolve in a gallon of water. Some commercial grades upon dissolving will flocculate unless the water is slightly acid and, as a result, may not be completely absorbed by the tree or pole.

Zinc chloride does not usually discolor wood and is generally only slightly corrosive to galvanized iron (2). Aluminum tags used on stakes impregnated with the salt, however, are quickly destroyed. Zinc chloride has a tendency to keep wood that is in or on the ground abnormally wet but possibly not so much so as copper sulfate.

A qualitative field test (23) for zinc chloride in wood can be made by spraying or brushing the wood surface with a mixture of 1-percent solutions of potassium ferricyanide ($\text{K}_3\text{Fe}(\text{CN})_6$) and potassium iodide (KI) and a 5-percent solution of soluble starch. A dark-blue color reaction reveals the presence of the preservative. Where no zinc chloride is present, the color of the wood remains unchanged.

Zinc chloride will prevent the breeding of bark beetles and damage by sawyers, termites, and wood-destroying fungi; however, it will not prevent ambrosia beetles from making pinholes in treated wood. While these holes may not structurally weaken the wood there is discoloration about the holes, and the holes permit the infiltration of moisture, increasing the chances for leaching.

Zinc chloride was used in these studies only in water solutions. Injection amounts of from 0.1 pound to 1.75 pounds per cubic foot of wood were applied, and bolts from trees and poles treated at these various dosages were set out for service tests. The dosage of 1 pound of the salt and $\frac{1}{2}$ gallon of water per cubic foot of wood gave adequate protection and is recommended as a practical minimum for sap-stream treatments of trees up to 8 inches in diameter.

CHROMATED ZINC CHLORIDE

Chromated zinc chloride is a combination of 81.5 percent zinc chloride (ZnCl_2) and 18.5 percent sodium dichromate ($\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$) rather recently developed and used for commercial wood preservation. It is a gray, crystalline, deliquescent mixture that must be kept in tightly sealed containers for dry storage. No doubt solutions of 50 percent strength can be kept satisfactorily. Upwards of 16 pounds of the salt will dissolve in 1 gallon of water.

Chromated zinc chloride, like zinc chloride, is slightly corrosive to metal (2) and does not discolor wood but it tends to keep the wood wet. It costs approximately 15 cents per pound in bulk.

The color test used for zinc chloride (23) is applicable with this preservative. It is, however, a test for the zinc only and not for the sodium dichromate.

Service bolts from pines treated with chromated zinc chloride in amounts of from 0.125 to 1 pound per cubic foot of wood are in excellent condition after 5 years in the ground, damage being limited to unstained pinholes caused by ambrosia beetles. The injection dosage of $\frac{3}{4}$ pound in $\frac{1}{2}$ gallon of water is a satisfactory minimum for practical wood preservation. This combination has the advantage of being possibly more resistant to leaching than zinc chloride used alone.

SODIUM ARSENITE

Sodium arsenite ($\text{Na}_2\text{HASO}_3 \cdot x\text{H}_2\text{O}$) is a hygroscopic, colorless, crystalline, or white, powdered salt that has been used as a wood preservative for several years with promising success. It can be purchased for approximately 8 cents per pound in bulk lots.

Sodium arsenite is very soluble in water. Being very poisonous, it must be used with caution. It is attractive but harmful to domestic and wild animals, and must be guarded from them.

Sodium arsenite is not corrosive to metal and does not stain wood, but wood treated with it and lying on the ground tends to remain abnormally wet.

No color tests were used for sodium arsenite in treated wood.

Bark beetles cause no injury to trees treated with sodium arsenite; sawyers, however, readily attack them, but with no resulting injury other than numerous egg scars on the bark. Ambrosia beetles penetrate the wood, but the ambrosia fungus stains it only lightly.

Sodium arsenite was used at a few different injection dosages; the effective minimum was $\frac{1}{2}$ pound of salt in $\frac{1}{2}$ gallon of water per cubic foot of wood. Service bolts, from trees treated with this and higher dosages, in and on the ground for 6 years, are still in good condition. In general, however, the results of treatment have been less satisfactory than those with copper sulfate or zinc chloride.

MERCURIC CHLORIDE

Mercuric chloride (HgCl_2), or bichloride of mercury, commonly referred to as corrosive sublimate, has been used in Europe as a wood preservative for many decades, but in this country its use has been very limited.

Its acceptance as a preservative in the United States is generally frowned upon because it is extremely poisonous and is highly corrosive to metal.

Mercuric chloride is a colorless crystalline, or white granular, or powdered salt, soluble in water at a rate of over $\frac{1}{2}$ pound per gallon. It costs over \$2 per pound.

Being very poisonous, this salt must be used with extreme caution. Domestic or wild animals should not be given an opportunity to drink or lick it.

Mercuric chloride does not discolor wood, but, like copper sulfate, it is corrosive to iron and tends to keep the wood wet. It can be kept safely in glass, wooden, or rubber containers.

Field chemical tests (4) for mercuric chloride can be made by lightly coating the wood surfaces with a solution of hydrogen sulfide (H_2S). The resulting black precipitate discolors the treated wood, indicating the presence of the preservative; the failure to discolor indicates an absence of the salt.

In these investigations mercuric chloride was used in amounts as low as 0.004 pound and as high as 1.5 pounds per cubic foot of wood. Although very toxic, the salt did not provide satisfactory protection even when used at the highest dosage. Where present, even in very small amounts, the chemical serves as an excellent preservative, but chemical analyses and other evidence indicate that, when injected by sap-stream methods, the salt concentrates near the point of absorption and distributes only a short distance. The cause of such poor distribution was not determined but may be a chemical reaction between the mercuric chloride and the wood cell or wood-cell inclusions, forming a precipitate or causing some reaction that interferes with sap flow.

Wood impregnated with mercuric chloride is not damaged by bark beetles, termites, sawyers, or wood-destroying fungi. Ambrosia beetles, however, will penetrate a short distance into the treated wood.

Aside from its very poisonous qualities, mercuric chloride is still considered an impractical chemical for sap-stream treatments because it fails to spread the full merchantable length of the tree or pole or even a reasonable part of the length.

AMMONIUM BIFLUORIDE

Ammonium bifluoride (NH_4HF_2) is a white, crystalline, deliquescent salt, which is very soluble in water.

Because it breaks down into hydrogen fluoride (HF), which can be very dangerous, ammonium bifluoride should be handled with caution.

The salt does not discolor wood but tends to hasten its drying. It etches glass and hence should be stored and used in metal, wooden, rubber, or paraffined containers. It costs approximately 15 cents per pound.

A field test for the presence of ammonium bifluoride (5) in wood consists of spraying or brushing the wood with 5 grams of zirconium oxychloride ($\text{ZrOCl}_2 \cdot 8\text{H}_2\text{O}$) in 500 cc. of water, to which solution there has been added 2 grams of sodium alizarine sulfonate ($\text{C}_{14}\text{H}_5\text{O}_2(\text{OH})_2\text{SO}_3\text{Na} \cdot \text{H}_2\text{O}$) dissolved in 40 cc. of concentrated hydrochloric acid (HCl) and 460 cc. of water. Wood containing the preservative turns yellow and the untreated wood turns magenta.

Ammonium bifluoride was applied in a small number of treatments during 1939 and 1940, which apparently is the limit of its use as a preservative. Ammonium fluoride (NH_4F), on the other hand, although not so satisfactory, had been used somewhat extensively in earlier tests.

Injury by insects and fungi is nearly negligible. Ambrosia beetles penetrate the wood only lightly, and damage by sawyers is limited to a very few egg scars.

Because of the limited service tests it has had, ammonium bifluoride is listed only as a promising wood-preserving salt. Otherwise it has all the indications of a very satisfactory chemical for use in sap-stream injection treatments.

COPPER CHLORIDE AND ARSENIC ACID

Copper chloride ($\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$) was combined with arsenic acid (H_3AsO_4) in a water solution and tested as a preservative. Copper chloride, a green to bluish-green, crystalline salt, is deliquescent in moist air (efflorescent in dry air) and dissolves in water at the rate of approximately 10 pounds per gallon. It costs about 21 cents per pound. Arsenic acid costs approximately 20 cents per gallon.

Arsenic acid, at 75-percent strength a clear liquid, is very soluble in water and extremely poisonous.

The solution of these two chemicals is prepared by dissolving the copper chloride in water and then adding the arsenic acid. Copper arsenate ($\text{Cu}_3(\text{AsO}_4)_2 \cdot 4\text{H}_2\text{O}$) and hydrochloric acid (HCl) are formed by this combination. Upon drying, as occurs after the solution is absorbed by the wood, the hydrochloric acid evaporates, leaving a residue of poisonous insoluble copper arsenate.

No color test to reveal the presence of copper arsenate in treated wood was used.

A few impregnations of pines were made in 1940 with a preparation made up of 1 part of copper chloride, 8 parts of arsenic acid, and 15 parts of water, by weight. Two injection dosages were used, one of 0.8 pound and another of 1.6 pounds of copper chloride per cubic foot of wood.

The results of these treatments thus far are very promising. Absorption of the chemical is rapid and the absence of insect and fungus injury, even that by ambrosia beetles, indicates that the solution is an effective preservative. The wood dries out quite rapidly and without checking. The dried chemical is insoluble, hence does not leach out.

AMMONIUM COPPER ARSENITE

Ammonium copper arsenite is a strong ammoniacal solution of copper arsenite (CuHAsO_3) containing an excess of copper hydroxide

($\text{Cu}(\text{OH})_2$). After it is distributed in the wood the ammonia volatilizes, leaving insoluble copper arsenite which stains the wood green. Of the few trees treated with this chemical, some were left standing while the others were cut into bolts which were set in the ground. Practically all are still holding up very well after 10 years. Possibly deserving to be rated as commendable, this chemical is listed as only promising because the tests have been limited to a few treatments.

ZINC METAARSENITE

Zinc metaarsenite ($\text{Zn}(\text{AsO}_2)_2$), another chemical that is only slightly soluble in water, results from the evaporation of acid from a solution of zinc oxide (ZnO) and arsenic trioxide (As_2O_3) in water acidified with acetic acid (H_3AsO_4). Several trees were treated in 1930 and 1931 with this solution. Some of them were left standing and are still in good condition, others were sectioned and set out in the ground and are holding up fairly well. The qualities of the preservative do not appear so good as those of ammonium copper arsenite, but they are satisfactory and encouraging enough to place this chemical tentatively on the list of promising preservatives. At present the prepared preservative is unobtainable in quantities suitable for commercial use (24).

INCIDENTAL EFFECTS ON THE WOOD

WATER CONTENT OF SALT-TREATED WOODS

Some of the chemicals, among them copper sulfate, are not deliquescent, yet impregnated poles and felled trees and bolts from them invariably have a greater water content after several years' service in contact with soil than a week or two after treatment. The wood looks and feels wet and is heavier than untreated wood. Even treated poles stored under cover for 2 years were found to have a moisture content in excess of that normally present in air-seasoned untreated wood. This likewise holds true for the hygroscopic salts like zinc chloride and sodium arsenite. The excessive wetness following certain treatments, especially in the case of large trees, apparently results in a loss of the chemical from the outer rings, an outer shell of unprotected wood being left. The probability that these chemicals keep the wood wet may be a primary reason for the abundant attacks and deep penetrations of ambrosia beetles that usually occur in treated wood. In contrast to these results, the wood from trees treated with ammonium bifluoride and with copper chloride and arsenic acid appears to become unusually dry. These latter treatments, however, have been in service only since 1940 and the early results are merely indicative.

CHECKING OF SALT-TREATED WOODS

Seasoning checks in woods impregnated with preserving salts by sap-stream methods have thus far been insignificant. This is especially noticeable in treatments that have been in field service and in the poles that have been seasoning under cover. It is believed that even with further drying, checking will continue to be insignificant.

Favorable evidence along these lines is revealed by the results of the chemical-seasoning studies (20 and 22) conducted by the Forest Products Laboratory of the U. S. Forest Service at Madison, Wis.

BARK-HOLDING PROPERTIES

Contrary to preliminary reports (13), there is no satisfactory evidence that any of the chemicals used have reliable bark-holding properties. Well-impregnated trees will retain bark longer than untreated ones, but usually not with any degree of permanence. Occasionally, however, for no understandable reason the bark will remain tight and resist all efforts to remove it. This is especially true of treatments with very high dosages ($2\frac{1}{2}$ pounds per cubic foot of wood) of copper sulfate.

The phloem of most treated trees also dries and contracts, disconnecting the bark and xylem, but the wood, drying slowly, does not shrink away from the bark so rapidly or so much as does untreated wood. Further, as the treated wood does not check, the bark is not split, but generally is left in one piece which can be slipped off the stem as a sheath. It will not slough off in small patches unless mechanically broken.

RELATIVE DURABILITY OF TREATED PINES AND HARDWOODS

Bolts from pines impregnated with chemicals by sap-stream methods have held up in service considerably better than those from hardwoods similarly treated. This preservation differential is due in large part to the difference in durability between sapwood and heartwood of pines and hardwoods. The sapwood of the pines and the hardwoods used in these studies is not durable; and the heartwood and transition wood of yellow poplar and of most of the other hardwoods used likewise is nondurable. The heartwood of the pines used, on the other hand, is relatively durable. As a consequence, bolts, posts, and poles from treated pines are generally well protected from destructive insects and decays. The heartwood is protected naturally by pitch infiltration and the sapwood by the injected chemical. Treated hardwoods of the species used in these tests, however, commonly have a well-preserved shell of sapwood around a core of unprotected, and naturally nondurable, heartwood or transition wood which is subject to attack by insects and decay at the unprotected ends. Dipping the ends of such hardwoods in an approved grade of coal-tar creosote (24) or soaking them in a solution of the injected salt appreciably increases the usefulness of the treatments. This would not be necessary with species of hardwoods that have naturally durable heartwood.

SEASONS FOR TREATING TREES

The majority of sap-stream treatments were made in the summer (June through September). For comparative purposes, however, series of treatments were made with a few chemicals during all four seasons.

Chemical absorption and distribution within pine trees take place throughout the year. Hardwoods can be treated only during late

spring and summer when their crowns are in green foliage, or in the early spring as the buds are swelling.

The effect of the season of the year (air temperature) on the treatment of trees seems to be reflected in the time rate of chemical absorption. Ordinarily, with summer treatments the preservative solution is taken into a pine or yellow poplar within 2 to 6 hours. During winter, exclusive of freezing weather when the salts crystallize out of solution, the absorption in a pine often takes over a day. Chemical distribution within the wood of a treated tree also reflects the effect of the season of the year on sap-stream treatments. The rise of the chemical up the stem and its radial movement is rapid in the summer, but slow during the colder months.

To a slight degree absorption of a chemical solution is influenced by time of day—apparently a direct result of transpiration changes. The intake of the solution increases from sunrise to mid-afternoon. It then decreases, and by nightfall it becomes negligible, remaining so until morning.

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